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UC-721

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Prepared for the U.S. Department of Energy
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Summary

Manipulator system cold validation testing (CVT) was performed in support of the Fuel Retrieval System (FRS) Sub-Project, a subtask of the Spent Nuclear Fuel Project at the Hanford Site in Richland, Washington. The FRS will be used to retrieve and repackage K-Basin Spent Nuclear Fuel (SNF) currently stored in old K-Plant storage basins. The FRS is required to retrieve full fuel canisters from the basin; clean the fuel elements inside the canister to remove excessive uranium corrosion products (or sludge); remove the contents from the canisters; and sort the resulting debris, scrap, and fuel for repackaging. The fuel elements and scrap will be collected in fuel storage and scrap baskets in preparation for loading into a multi canister overpack (MCO), while the debris is loaded into a debris bin and disposed of as solid waste.

The FRS is composed of three major subsystems. The Manipulator Subsystem provides remote handling of fuel, scrap, and debris; the In-Pool Equipment subsystem performs cleaning of fuel and provides a work surface for handling materials; and the Remote Viewing Subsystem provides for remote viewing of the work area by operators. There are two complete and identical FRS systems, one to be installed in the K-West basin and one to be installed in the K-East basin. Another partial system will be installed in a cold test facility to provide for operator training.

The purpose of CVT was to provide validation of equipment layout and functionality and validate the FRS process logic. The test program was set up to accomplish these objectives through cold (non-radiological) testing of the Schilling Robotic Systems' Konan manipulator system. The K-West basin (KW) manipulator system, the K-East basin (KE) equipment operations center (EOC) and close circuit television system (CCTV), a prototype long pole tool for recovering dropped fuel pieces, a process table mockup, and various other major process equipment mockups were used for these tests. The Konan manipulator system was installed in a wide, elongated pit at the Hanford 305 Building Equipment Testing Laboratory (ETL) during February 1998 and was subjected to several months of burn-in testing prior to turnover for CVT, which took place in early September. Formal testing began September 18.

A grating platform was installed over the pit at a prototypic elevation referenced to the manipulators and process table below. There were also mockups of the Primary Clean Machine (PCM) and the MCO basket queue located in correct position in relation to the process table. These were included in an attempt to evaluate travel room and relative positioning during normal operations. To provide additional validation, trained K-Basin Nuclear Process Operators (NPO) were utilized to perform the CVT test functions. These individuals possess the required expertise for in-basin fuel handling activities associated with K-Basin fuels and provided valuable insight to the testing program and results. The operators chosen represented an average shift crew of four, where two of the operators were very experienced and exceptionally competent and the other two had significantly fewer hours of experience and represented more of the average competence level expected for future manipulator operators.

To validate both the equipment and the FRS process logic, the basic fuel handling process was performed using four distinct operating scenarios. The first was for equipment validation and was set up to use both

manipulators in the production mode to process a single canister consisting of a standardized mix of 14 dummy fuel assemblies, which is referred to as the "standard canister". The production mode refers to processing the fuel without performing any inspections on the individual fuel assemblies. Typically, the goal of the production mode is to move the fuel and repackage it as quickly as possible. The remaining three scenarios, referred to as process validation runs, were all designed to validate the FRS process logic. This was accomplished by setting up four canisters of 14 dummy assemblies each and included the standard canister.

The first process validation test used both manipulators in the process validation mode, which is where each and every piece of fuel is inspected for sludge/oxide adherence and/or gross physical damage in order to validate the fuel cleaning process. The second process validation test again used both manipulators, this time in the production mode, where no inspections were performed. The fuel was simply sorted, separated, and loaded into the MCO baskets. The third process validation test used only a single manipulator (north arm only) to process the fuel, also in the production mode.

For the dual manipulator tests the basic process was broken into two logical sub-processes:

- North table operations; where fuel sorting, disassembly of full length fuel elements, separation of fuel segments less than three inches long (scrap) from the remainder of the fuel, scrap basket loading, debris separation and loading, and finally transferring the good fuel down to the south table ramp, takes place.

- South table operations were completely concentrated on fuel basket loading, including checking each outer element for basket socket fit in the go no-go gage.

A total of 16 test runs were performed where the equipment validation tests confirmed that the Konan manipulator and the prototype support tools can perform the required processing steps for K-Basin fuel recovery and re-packaging. Process validation tests verified that the time required to process a single MCO basket (Mark IA) is approximately 4 to 4-1/2 hours, which is significantly better than the maximum required time of 12 hours per MCO basket.

Abbreviations and Acronyms

BNFL	British Nuclear Fuels Limited
CDR	Conceptual Design Review
CSB	Canister Storage Building
D&D	Decontamination and Decommissioning
DESH	Duke Engineering Services Hanford
DOE	Department of Energy
EOC	Equipment Operations Center
ETL	Equipment Testing Laboratory
FRS	Fuel Retrieval System
ID	Inside Diameter
IWTS	Integrated Water Treatment System
MCO	Multi Canister Overpack
NPO	Nuclear Process Operator
OD	Outside Diameter
PCM	Primary Clean Machine
PNNL	Pacific Northwest National Laboratory
SNF	Spent Nuclear Fuel
SRS	Alstom Automation Schilling Robotics
VCR	Video Cassette Recorder
WHC	Westinghouse Hanford Company
XXS	Double Extra Strong

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Introduction

This document describes cold validation testing of the Fuel Retrieval System (FRS) Manipulator Subsystem, which is part of a much larger validation effort for the full FRS. Cold validation testing was performed in support of the FRS Sub-Project, a subtask of the Spent Nuclear Fuel Project at the Hanford Site in Richland, Washington. FRS test requirements are contained in HNF-SD-SNF-TP-027, "Test Plan and Strategy for the Fuel Retrieval Subproject" and manipulator system cold validation testing was performed to a formal released test procedure (Reference 4). A brief summary of the general FRS process is included in greater detail in Appendix G of this report.

The FRS will be used to retrieve and repackage K-Basin Spent Nuclear Fuel (SNF) currently stored in old K-Plant storage basins. The system will be used to clean and remove fuel from the fuel storage canisters, repackage it into new storage baskets, and transfer the baskets into a multi canister overpack (MCO). Once inside the MCO the fuel will undergo a cold vacuum drying process before the complete package is transferred for interim dry storage at the Canister Storage Building (CSB), also located on the Hanford Site. The FRS is required to retrieve full fuel canisters from the basin; clean the fuel elements inside the canister to remove excessive uranium corrosion products (or sludge); remove the contents from the canisters; and sort the resulting debris, scrap, and fuel for repackaging. The fuel elements and scrap will be packaged into MCO fuel storage and scrap baskets in preparation for MCO loading, while the debris is loaded into a debris bin and disposed of as solid waste.

Duke Engineering Services Hanford (DESH), formerly Westinghouse Hanford Company (WHC), was contracted to provide a retrieval system for safe repackaging of spent nuclear fuel in the K basins. DESH in turn let a subcontract to British Nuclear Fuels, Limited (BNFL) to provide design performance specifications for use in procurement of systems and equipment. In addition, a development test program was used in the design process to provide design information where experience and calculations could not provide or confirm the design basis (References 1 and 2). As a follow up to development testing a validation test program was implemented to confirm basic design assumptions and validate both the equipment design and the process logic for fuel recovery.

Pacific Northwest National Laboratory (PNNL) was requested to coordinate and lead the testing and computer simulation needs for development of the fuel handling retrieval system and for the validation test program. BNFL provided the applicable test specifications, indicating specific design needs, and tests were conducted in the Equipment Testing Laboratory (ETL), located in the 305 Building at Hanford. The ETL provided necessary facility space, test equipment design support, fabrication, engineering, and technician support for the FRS testing program.

The first phase of FRS testing was development testing, which was used to provide proof of concept and criteria, optimize equipment layout, initialize the process definition, and identify special needs/tools and required design changes in support of performance specification development (References 1 and 2).

Development testing was utilized in design of the primary cleaning machine (PCM), the canister decapper station, the stuck fuel station (canister slitter), the manipulator system, the remote CCTV viewing system, and many associated manual, or long reach, tools. In addition, development testing played a key role in developing a fuel handling and packaging process.

The second phase of FRS testing was cold validation testing. This was confined specifically to the manipulator system, the CCTV system (EOC), their respective interfaces, and the actual fuel handling and packaging process. Separate, individual validation test programs were developed for validation of the PCM, decapper station, and stuck fuel station designs. These test programs were also scheduled for fiscal year 1999. This report is limited to cover cold validation testing of the manipulator system only, which was performed in September 1998.

Test Objectives

The objective of Cold Validation Testing was to validate the final manipulator system design and the FRS fuel handling process as it applies to the process table. To ensure that the test procedures accomplished this task, they were developed, reviewed, approved, and released as a SNF controlled document. Final approval and distribution was accomplished using the Engineering Data Transmittal (EDT) system with final approval by the FRS Design Authority, the SNF-FRS Project Manager, SNF QA, the K-Basins Operations Manager, and the Engineering Laboratory Manager. Prior to distribution for approval, the procedures went through a rigorous review process, which included reviews by key project, operations, and startup staff. The approved test procedures were administered by the FRS Test Engineer and performed by qualified Nuclear Process Operators from the 100K Area operations crew.

To meet the general goal of cold validation testing, several sublevel objectives had to be met. These objectives were as follows:

- Prove that the equipment can adequately perform the required process steps for fuel repackaging.

- Provide validation that the FRS process description is viable and/or provide recommendations for process adjustments.

- Establish real-time production time lines based on actual performance times.

- Establish and/or refine basic equipment operating procedures.

- Establish and/or refine recommendations for hands-on operator time working the manipulators.

Test Method and Equipment

Test Method

The methodology used in CVT split the testing into the following major categories.

- <u>Equipment Validation</u>
- <u>Process Validation</u>

Equipment validation was performed to demonstrate that the system was able to perform all the basic functions required of it, while process validation focused on validating the fuel handling process as described in the FRS process description. In both cases, the throughput time was the major data point for performance comparison. During equipment validation testing the single standard canister was processed by each of two teams of two operators, where the test began with the standard canister dumped onto the north table ramp and concluded when the last piece of material was loaded into the appropriate container. There were a total of four equipment validation test runs where the operators switched places for their second run so that each operator ran each of the two manipulators during a test run.

Test Equipment

Cold validation testing was conducted in a non-radiologically controlled area and no radiological materials were used in any of the tests. A full scale, semi-prototypic mockup of the K-Basin processing area was erected in the 305 Building dry pit by NHC Engineering Laboratory personnel. It included mockups of the process table, the MCO scrap and fuel baskets, the primary clean machine (PCM), and a basin fuel rack. Actual Mark II fuel canisters, made up of two cylindrical cans or barrels joined together by an upper and lower lifting trunnion (ref. Figure 7), were used for CVT production simulations. The fuel was simulated using heavy wall pipe with similar diametric characteristics for both inner and outer elements, where the full-length dummy fuel elements were cut to 26 inches long, to simulate Mark IV fuel. The FRS Design Authority agreed that these tests adequately bounded the scope of canister and full types that FRS is designed to handle.

The mockup was set up in a prototypic arrangement, with component spacing and relative elevations being as accurate as could reasonably be achieved. To simulate basin monorail operations, a long-pole grapple, or hook, was deployed from an overhead crane for lifting operations such as retrieving fuel canisters and transporting them to the process table. In addition to the test article, the actual K-West production manipulator system, the K-East CCTV system and EOC racks were also installed in the mockup to complete the test set up.

The major test article was the K-West manipulator system, which includes two manipulator arms, two bridge/mast assemblies, the two target PCs (control system computers), and two master controller units (MCU). In addition to the K-West items, the EOC rack module, Basin Area J-Box, Hydraulic Distribution Manifold, hose/cable management system (e-chain), and the Hydraulic Pump Unit (HPU) for the training manipulator system were installed. These are all integral components to the manipulator system; however, these items are generic in nature and do not require specific component testing. This support system will remain in place after the K-West manipulator system has been transported to the basins for deployment. It will be used to perform run-in testing on the K-East manipulator system and then, later, for operating the training system.

The same wood process table mockup used in earlier development testing was again used during cold validation testing (Figure 1). Some minor modifications were included to adapt the table to the dry pit mockup area, such as adding longer legs and increased cross bracing to the supports. In addition, some small sections had to be cut out of the table to allow it to fit into the pit area. None of these modifications affected the normal process areas of the table. In addition to the table, the MCO fuel basket, MCO scrap basket, fuel basket back light, and the fuel basket lazy susan used, or developed, during development testing were also used during cold validation testing.

A plywood mockup was used to simulate the PCM in the test system layout and an abbreviated version of a basin fuel rack was set up just north of the PCM. The fuel rack, shown in Figure 2, held three Mark II fuel canisters, which were filled with 14 full-length dummy fuel assemblies (inners and outers). A fourth canister described as "the standard canister" included a mix of "broken" fuel elements, debris, scrap fuel, and full-length elements. The standard canister was developed for development testing and was used again in cold validation testing as a production standard for comparative purposes.

The standard canister makeup was based on K-East fuel condition as described in ECN 191405 (included in Appendix F) and is described in Table 1. It was made up of this mix of simulated scrap, debris, broken fuel, and full- length fuel. For control purposes, the standard canister contents were painted white. Figure 3 shows the contents of the standard canister dumped onto the north end of the process table.

TABLE 1. FRS Standard Canister Makeup.

• 10 full length inner elements • 10 full length outer elements • 2 half length inner elements • 2 half length outer elements • 14 pieces of inner element under 3" in length	• 14 pieces of outer element under 3" in length • 3 one-third length inner elements • 3 one-third length outer elements • 1 old glove (debris) • 1 screwdriver (debris)

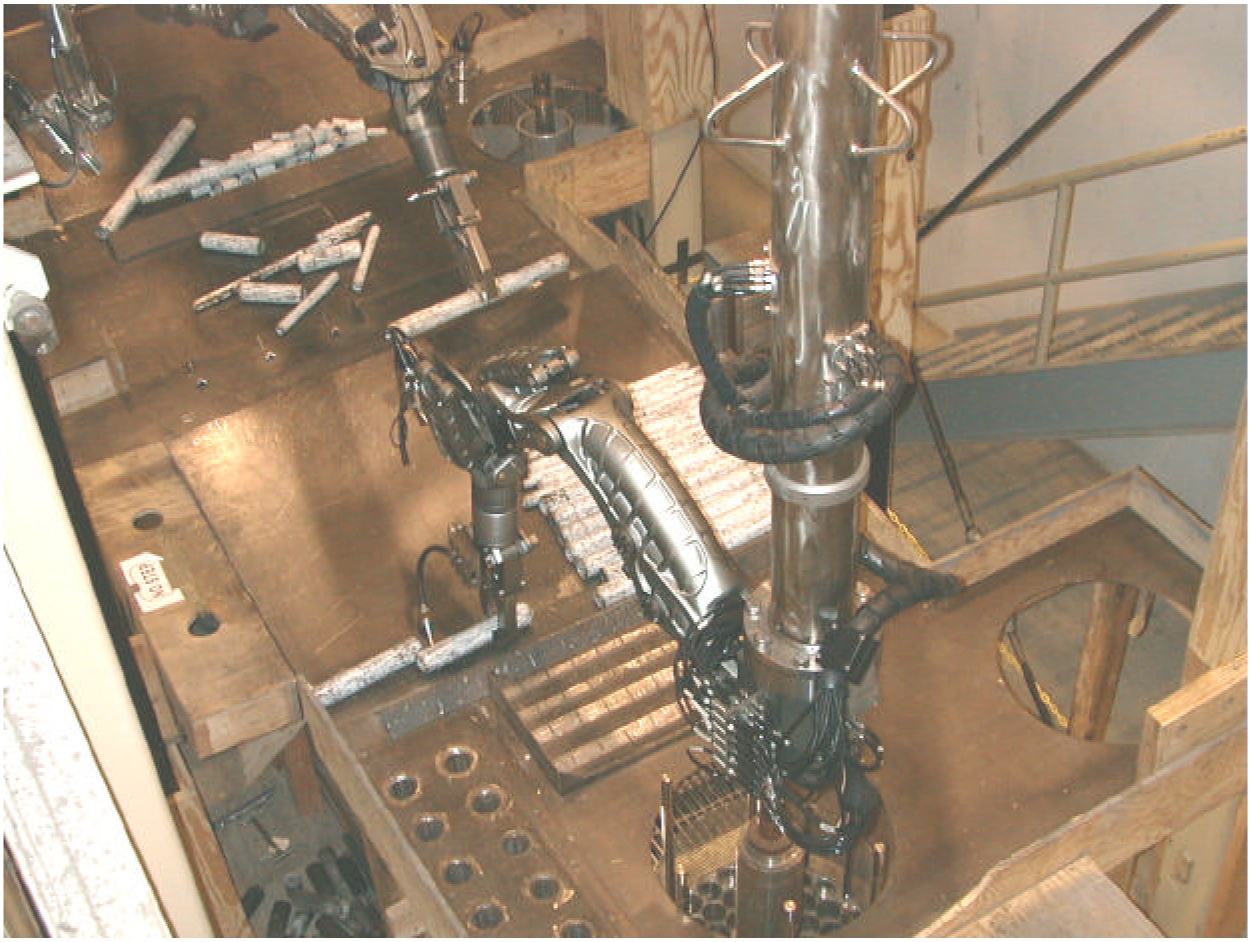

Figure 1. Process Table Mockup.

This approach, using the standard canister, puts all the broken fuel, scrap, and debris into one canister, which equates to approximately 25% of the fuel in this single canister being in one or more pieces. When performing single canister test runs this puts an ultra conservative condition into the test, which easily bounds the expected normal condition with no adverse interpretation of production results. In contrast, when the other three canisters are added to the test mix, the percentage of total elements in one or more pieces is closer to 7%. This gives a relatively close approximation to the expected gross fuel makeup in K-East, where the expected percentage of broken fuel is approximately 10%. For K-West it's 2%[1], with the raw average pieces per broken element equated to be 2.5. This mix was adjusted to three pieces per element, two pieces per element, and an odd mix of scrap fuel less than 3 inches in length. The scrap was included to add fine motion handling and scrap loading requirements to the production simulation and does not necessarily correspond specifically to defined fuel conditions, where 12% of the defective fuel is expected to be loaded out in scrap baskets. The assumption used for CVT is that the entire quantity of scrap consisted of fuel pieces less than three inches in length and greater than one inch in length. Longer sections of fuel categorized as scrap are not a concern with regard to loading or handling functions and pieces less than one inch.

[1] Statistics taken from ECN 191405, page 4 of 6, Section B, See Appendix F

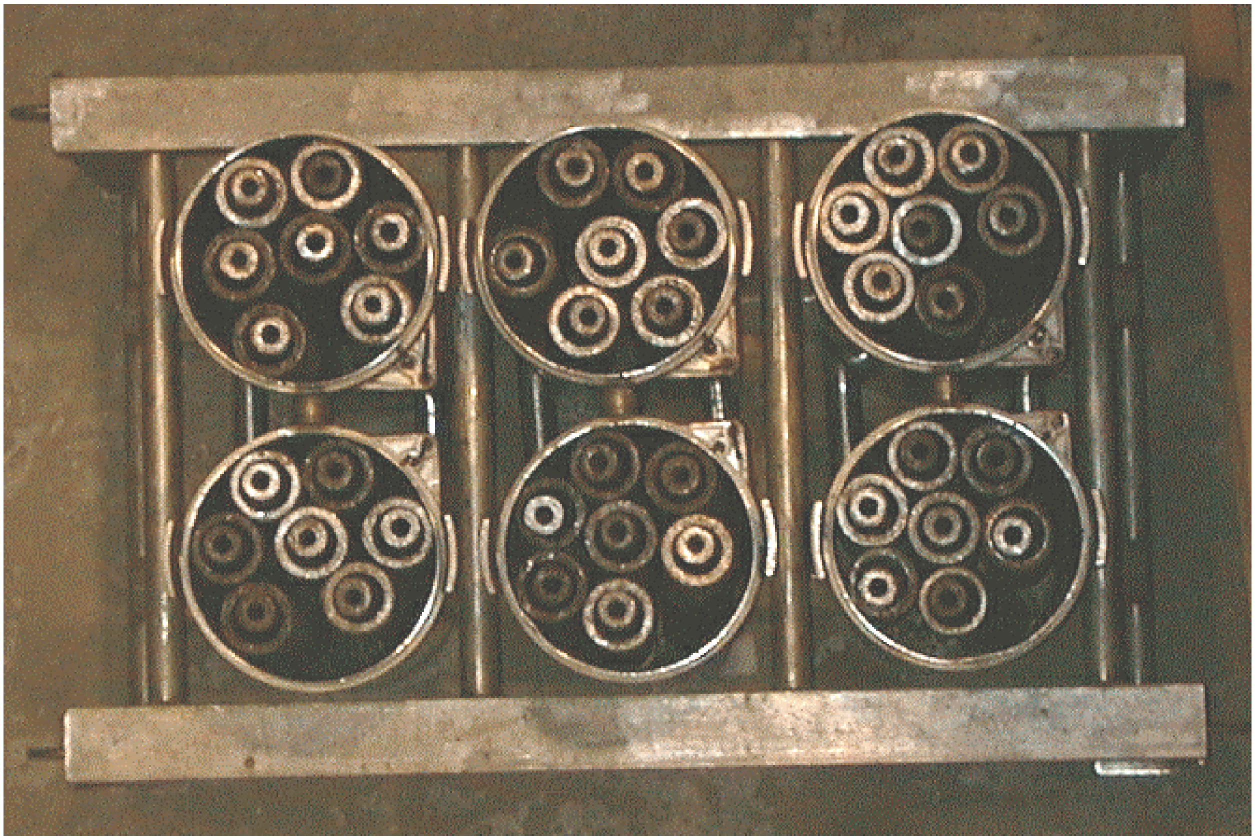

Figure 2. Fuel Rack Mockup with 3 Full Fuel Canisters.

Each fuel canister is made up of two individual barrels joined together by an upper and lower lifting trunnion. Each barrel holds 7 fuel assemblies resulting in each canister holding 14 assemblies.

will be treated as "fine scrap", which is being dealt with in a separate development and validation testing program and therefore not included in CVT.

The manipulator system used in CVT will be deployed in the K-West basin for fuel handling and repackaging, where each manipulator assembly includes a manipulator arm, a bridge/mast assembly, and a PC control computer. The bridge moves along a rail system that allows only straight line, forward and reverse movement. The bridge has the manipulator support mast suspended vertically from its center and remains stationary relative to the bridge. A helac is attached to the base of the mast and the actual manipulator arm attaches to the helac. The helac is a device that provides 360° rotational movement in the horizontal plane, which allows the manipulator to be deployed in any direction off the centerline of bridge travel. The manipulator arm is an electro-servo, teleoperated manipulator capable of a 375-lb. lift at full extension and is designed to simulate the joints of the human shoulder and arm. The system also includes two CCTV cameras, one mounted on the wrist of the manipulator arm and one suspended from the bridge. The bridge camera includes pan/tilt capability, while the wrist camera is a stationary mount.

Figure 3. Standard Canister Contents Dumped onto North Table Ramp.

The system design and manufacture was provided by Alstom Automation Schilling Robotics (SRS) under contract to DESH. The design utilized a modified version of the SRS Conan manipulator arm, which SRS labeled "Konan". In spite of the unique label for the K-Basin version, both spellings are seen in various manuals, drawings, and other associated documents and should be considered equivalent. SRS also supplied the hydraulic supply system, the PC control system, the software, and all power/hydraulic distribution systems required to operate the manipulator.

During development testing a revised manipulator jaw design was tested in the first prototype mode (Figure 4). The design was refined and a second-generation prototype was fabricated and installed on the test manipulators. The modified jaws extend farther out than the standard SRS jaws like two long fingers. This enables the operators to reach into areas that they could otherwise not reach into because of the bulk of the wrist and jaw mounting section. In addition, the extended jaws allow a higher degree of visibility of what is being picked up, primarily because the wrist blocks the view when the standard jaws are used. During CVT, the need for refinement of the prototype extended jaw design was identified, modifications were drawn up and a revised design issued as a formal fabrication drawing. The first two sets of the new jaw design will be procured for, and tested with, the K-West manipulators.

The device used to pick up full-length fuel elements and load them into the MCO fuel basket was the result of earlier development testing. SRS took the basic concept and developed a modified version of the tool and improved the actuation system to work with the Konan manipulator jaw (Figure 5). The basic principle is that of expanding a urethane spring outward against the inside diameter (ID) of a fuel element. The pressure applied creates sufficient friction to hold the fuel element during transfer into the fuel basket. Actuation of the manipulator jaw was used to actuate the device. A lever arm is attached to the manipulator in such a manner that when the jaws are opened, the lever is pushed away from the anchor point on the manipulator wrist. The lever has a cable pull assembly attached to it and when the lever moves the cable is taken up, which then pulls an end piece back toward the anchor point. The urethane spring is sandwiched between the anchor point and the end piece and when the cable gets taken up, the urethane spring gets compressed. The axial compression then expands diametrically against the ID of the fuel element. When the fuel element is acquired in this manner it can be lifted up and will hang vertically no matter what position the arm is in. This ability is critical for loading fuel elements into the basket. This device was included in CVT as a tool, but is also undergoing its own development and improvement program.

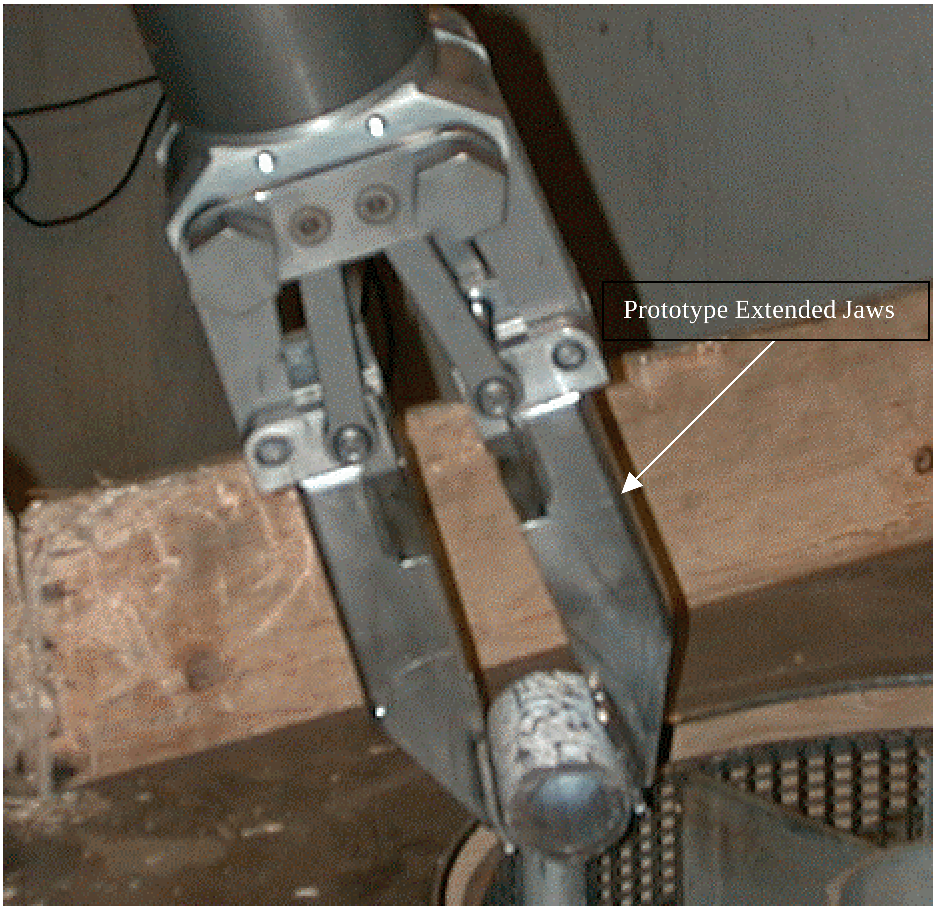

Figure 4. Extended Manipulator Jaws.

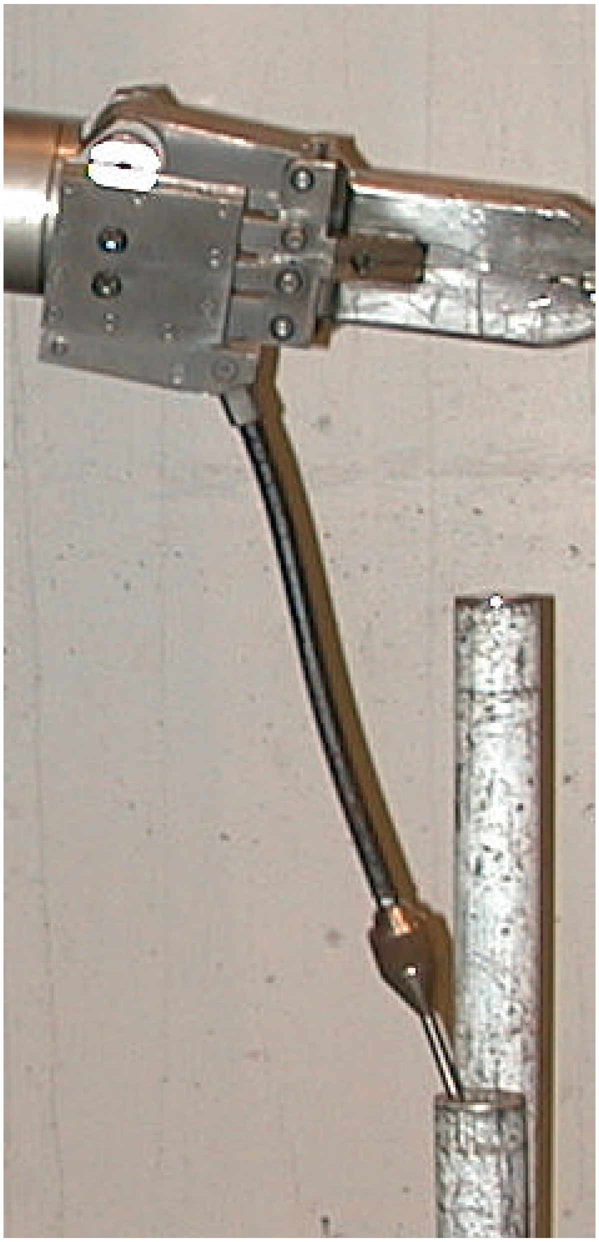

Figure 5. Fuel Grapple End-Effector.

All tests were performed using remote camera operations. The CCTV system procured for deployment in the K-East basin was set up in the test facility for CVT and early operator training. The CCTV system provided 12 cameras, including the two on each of the manipulators, and controllers for remote viewing capability. These cameras were deployed in the same manner and relative locations to be used in the basins. Both the camera and manipulator control systems were installed in the Equipment Operations Center (EOC) and testing was performed using the actual production control and viewing stations (Figure 6).

Figure 6. Equipment Operations Center.

Process Validation tests focused on the process and not on the equipment. Tests were performed in several different configurations and, as in equipment testing, each operator ran each of the machines at one time or another. Process validation tests also utilized a total of four fuel canisters rather than just a single canister. Using four canisters provided enough dummy fuel elements to fill a Mark IA fuel basket and leave eight fuel assemblies lying on the south table ramp. As in equipment validation, the tests began with the standard canister dumped onto the north table ramp. The other three loaded canisters remained in the canister rack until all the fuel dumped onto the north table ramp was moved to the south table ramp or loaded in the appropriate container. The second canister was then removed from the canister rack and dumped onto the north table ramp while the south manipulator continued to load fuel from the first canister into the fuel basket. The north manipulator had to be rotated to a due west position and parked in the center of the fuel inspection area of the table to provide sufficient clearance to dump the next fuel canister. The time taken to dump each successive canister was included in the production throughput times included in the test results. Every test run performed during CVT was video taped for additional documentation of test performance results.

Test Descriptions

Cold Validation Testing was made up of several individual test runs, each of which was performed as part of a standard test sequence. In total, there were three test sequences, each of which was designed to acquire pertinent data on specific operation and performance parameters. All three test sequences were built on one or the other of two basic test procedures (Reference 4). One test procedure represented the validation mode of operation, while the other represented the production mode. Copies of the test procedures are included in Appendix E of this report.

The CVT test procedures and sequences were built on knowledge gained from FRS development testing and ultimately on the FRS Process Description (Reference 3). Each of the three test sequences included several individual test runs, the results of which made up the aggregate data package for the test sequence. The three test sequences and a brief description of each are as follows:

- Equipment Validation
  Does the equipment perform the functions required of the process?
- Process Validation
  -Can the process be performed to meet the requirements of the following process modes?
  -Validation Mode – mode to be used during initial startup and operation of the FRS when efficacy of the process is being verified and key operating parameters are being optimized.
  -Production Mode – mode to be used for processing the bulk of the fuel once validation mode has been successfully completed.

In addition to the different test sequences, the Process Validation – Production Mode sequence was performed using both single-manipulator and dual-manipulator operating scenarios. In these two cases the tests were run with either one or both manipulators used to perform the normal fuel handling process. The dual manipulator process is the recommended standard operation and the single manipulator process is the fall back in the case where one of the manipulators becomes inoperable.

Equipment Validation Tests

This test sequence was intended to validate the equipment's capability to perform the necessary functions to process the fuel. As such, the primary focus of these tests was the equipment and its proper function.

The test sequence involved processing a single canister of dummy fuel elements, including simulated broken and scrap elements, from the north end of the process table to the south end of the table and loading each individual piece into the appropriate MCO basket. The canister contents included simulated debris, which was disposed of as described in the process description. Processing was performed using both manipulators, one to sort fuel on the north end of the table, load the scrap fuel and debris and a second manipulator to load full length fuel elements on the south end of the table. A limiting acceptance time of three hours was assumed based on results from early development testing in FY97 (Reference 2).

At the beginning of CVT, three practice runs of the equipment validation sequence were run. The practice runs were used to fully evaluate operator readiness to perform the battery of CVT tests. As expected, there was a mild learning curve during the practice runs, but the operators came up to full speed in a suitable time and regular testing commenced. For equipment validation a total of five test runs were performed, where the collected data included process throughput times, interruptions, exceptions, and system malfunctions. To readily assess the system's capability, tests were not stopped in the event of minor equipment problems. The definition of minor was applied to any occurrence that could be readily and quickly corrected. These included control system communications loss, control computer crashes, etc. In each case the interruption or problem was logged into the test exception log and the test run continued. Minor interruptions were included in the final process time recorded for each test run. It was determined during test preparations that such interruptions could be expected during production and that they were insignificant to long term production goals and certainly did not render the equipment unacceptable for its intended function.

Major equipment problems were also accounted for in the test exception log, but the test clock was stopped during the repair time for this level of interruption. In all cases the equipment test runs were restarted and completed. This type of interruption should not be expected during normal operations and for that reason they were diagnosed and corrected prior to restart of the test.

Process Validation Tests

The purpose of process validation testing was to validate the fuel handling process as described in the FRS process description. As such, the primary focus of these tests was on the process and the ease of which the operators could perform it.

In the process validation tests the fuel handling process steps required to process fuel from acquisition of the fuel canister to final loading of the MCO fuel basket were performed. To more accurately depict the actual process a total of four fuel canisters were used in the simulations. Four canisters were used because they held a sufficient quantity of fuel elements to completely fill the Mark IA fuel basket (48 assemblies) being used in the tests. The test run time included the time to move the remaining eight assemblies (eight inners, eight outers) onto the south table ramp as well. This provided sufficient data to more accurately estimate the loading time for the Mark IV fuel baskets, which hold 54 assemblies. Three canisters were filled with full length (no scrap or debris) dummy assemblies and set into a mockup canister queue, located just north of the Primary Clean Machine (PCM) mockup. The standard canister was used for the fourth canister and was dumped onto the north table ramp prior to starting each test run.

In all the process validation test runs the standard canister was the first of the four canisters processed and it was always dumped onto the north table ramp prior to starting the test. This set up the test run with one canister already dumped onto the ramp and three full canisters stored in the simulated queue. Test processing times included the time to dump each of the three queued canisters onto the north table ramp and to clear the empty canister away from the manipulator work area.

Figure 7. Dumping a Mark II Canister onto the Process Table North Ramp.

The general fuel handling process used in process validation testing started with sorting the standard canister fuel, scrap, and debris on the north end of the table, then moving the good fuel (pieces longer than three inches) to the south table ramp. After the good fuel was moved to the south table ramp, the south manipulator could be used to begin loading the fuel into the MCO fuel basket. The north manipulator would then be used simultaneously to finish sorting and loading the scrap and debris into the north scrap basket or debris bin. This process was repeated for each of the remaining three fuel canisters. In basket loading, the first fuel pieces to be loaded are the broken outer elements. These pieces of fuel get loaded first in order to provide more room for maneuvering the manipulator or the modified Peter's tool. The first step in this process is to recover the short, or broken, outer elements and stack them up in the measuring rack, where the overall length of broken outers can be determined. This sets up a nearly full-length column of fuel to load into one basket slot. Then the longest of the short pieces for each stack of broken outer elements were picked up and set into the go no-go gage, where they could easily be acquired with the manipulator fuel tool or grabbed with the Peter's tool. For the CVT, one of the broken outer elements was too short to load with the manipulator so the long-reach modified Peter's tool was used to load it into the basket slot (Figure 8). This short piece of outer element was usually the first to be loaded, with the other longer broken outer elements being loaded with the manipulator fuel tool. After loading these starter pieces, a full-length inner element was picked up with the manipulator jaws and placed inside one of the outer elements (Figure 10). The remaining pieces of this first broken outer element were slipped over the end of the inner element and dropped down in place, again using the manipulator jaws. This sequence was repeated until all the broken outer element pieces were loaded in the fuel basket. The next step was to use the manipulator to pick up the full-length outer elements from the south ramp and set them up in the go no-go gage. The go no-go gage is sized to verify that a fuel element will be able to be loaded into a fuel basket socket and allows the elements to be oriented in the vertical position. Once in the vertical position, the manipulator fuel tool was used to acquire an outer element and load it into an empty basket socket. After all the outer elements were loaded into the basket, the broken inner elements were picked up with the manipulator jaws and dropped into an outer element. Finally, the full-length inner elements were loaded into each remaining empty outer element so that each basket socket held a complete fuel assembly.

A basket-loading map was used to keep track of which sockets were loaded with each piece of dummy fuel for both inner elements and outer elements (Figure 11). The operator recorded what length piece was loaded into each socket as he loaded the piece into it. This keeps track of fuel pieces that cannot be easily seen once loaded and keeps track of where the empty sockets are in the basket. This becomes increasingly important as the basket becomes fuller as demonstrated in earlier development testing (Reference 2). It is possible to have an empty socket in the middle of several full sockets and not be able to see it from above. Without marking the map, an operator might assume that all the sockets are full and prematurely load the basket into the MCO. The map is also very useful for fuel accountability.

There were three variations of process validation testing performed during CVT. They were validation mode and dual manipulator-production mode, which use both manipulators as described above, and single manipulator-production mode, which uses only the north manipulator to perform all of the process steps.

Validation mode tests followed the validation mode fuel handling steps described in the FRS process description, which include all of the production mode operations described in the FRS process description plus mandatory fuel element separation and individual element inspection. For CVT the fuel element inspections included inspection of the scrap fuel pieces. Also, in validation mode tests the actual fuel separation ram and inspection stations were not available, so dummy elements were separated by simply dumping the inner element out of the outer element and onto the table. Simulated inspection steps were also included in the tests. Inspection simulations consisted of setting the dummy fuel piece onto the simulated inspection area and holding it there for five seconds. During validation mode testing, each and every piece of dummy fuel was "inspected" in this manner, including the scrap pieces.

Figure 8. Using the Modified Long Reach Gripper to Load Short Fuel.

Clockwise from Top Left: a) Operator Clamping Modified Peters Tool Jaw onto Fuel Element; b) Placing Short Outer Fuel Element Into Go/No-Go Gage; c) Loading a Short Outer Fuel Element Into MCO Fuel Basket; and d) Picking up a Dropped Piece of Inner Fuel Element.

Dual-manipulator production mode tests followed the standard production fuel handling steps and used both the north and south manipulator to separate and load the fuel. As described above, the north manipulator is used to sort fuel, scrap, and debris, separate the inner elements from the outer elements, load the scrap into the north scrap basket, load the debris into the debris bin, and transfer the acceptable fuel to the south table ramp. The south manipulator is used to gage the outer elements in the go no-go gage and to load the fuel into the fuel basket. The latter operation utilized the Schilling-designed manipulator fuel tool, or stinger. These test runs also included steps to transfer loaded fuel canisters from the simulated queue to the process table and dump each canister onto the north table ramp. Resultant test times are for completely loading a Mark IA fuel basket with 48 element pairs, including simulated broken fuel elements, and transfer of the remaining eight element pairs onto the south table ramp.

Single-manipulator production tests followed the standard production fuel handling steps but used only the north manipulator. The south manipulator was moved as far south as possible and "parked". In this operational set up, the north manipulator is used to perform all of the fuel handling and packaging steps, including loading the fuel with the manipulator fuel tool. As before, these test runs included steps to transfer loaded fuel canisters from the simulated queue to the process table and dump them onto the north table ramp. Resultant test times are for the time taken to fully load a Mark IA fuel basket with 48 element pairs, including simulated broken fuel elements, and transferring the remaining eight element pairs onto the south table ramp.

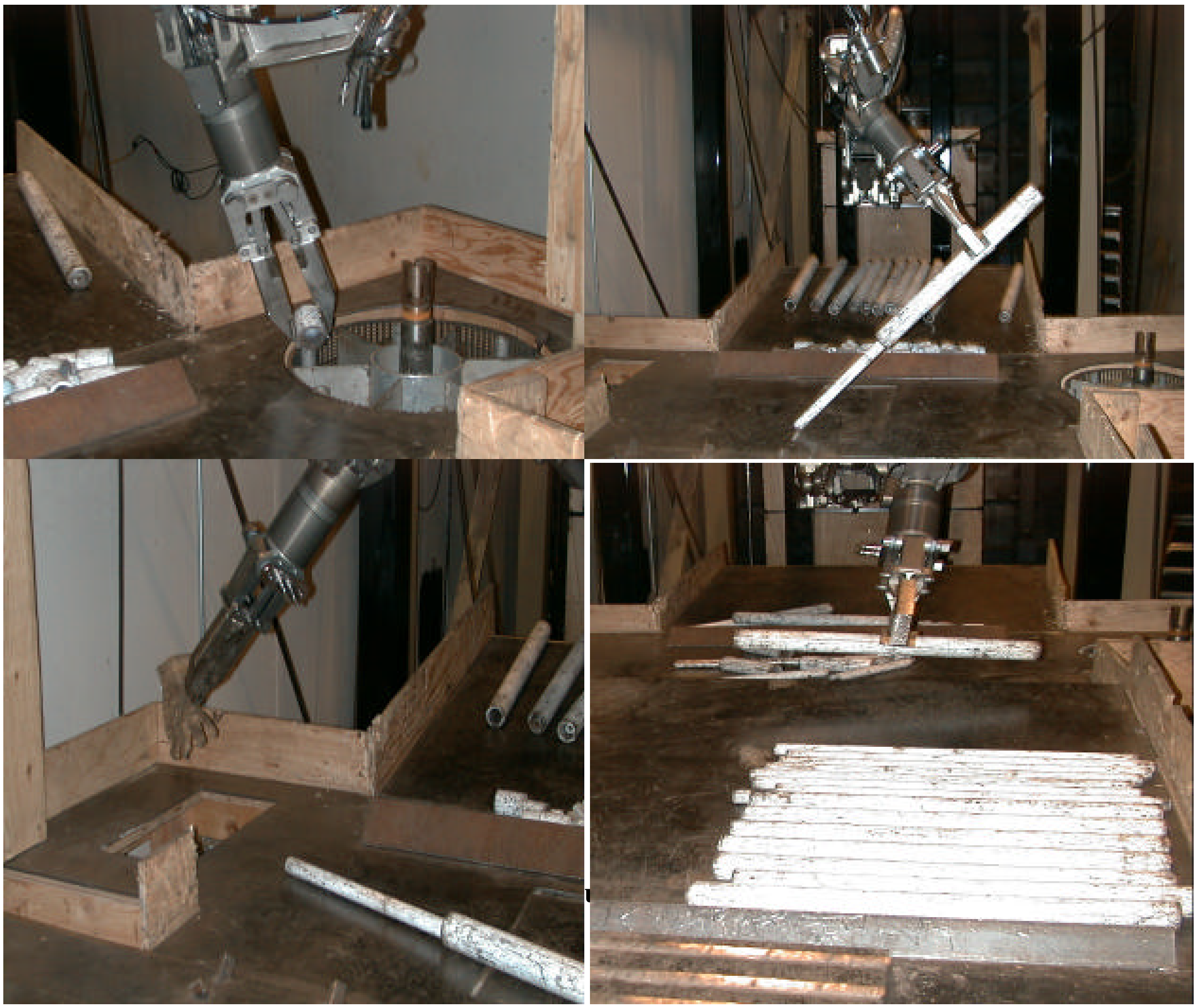

Figure 9. Manipulator Operations.

Clockwise From Top Left: a) Loading Scrap into North Scrap Basket; b) Separating an Inner Fuel Element from an Outer Element; c) Transferring Fuel to the South Table Ramp; and d) Loading Debris into Debris Bin.

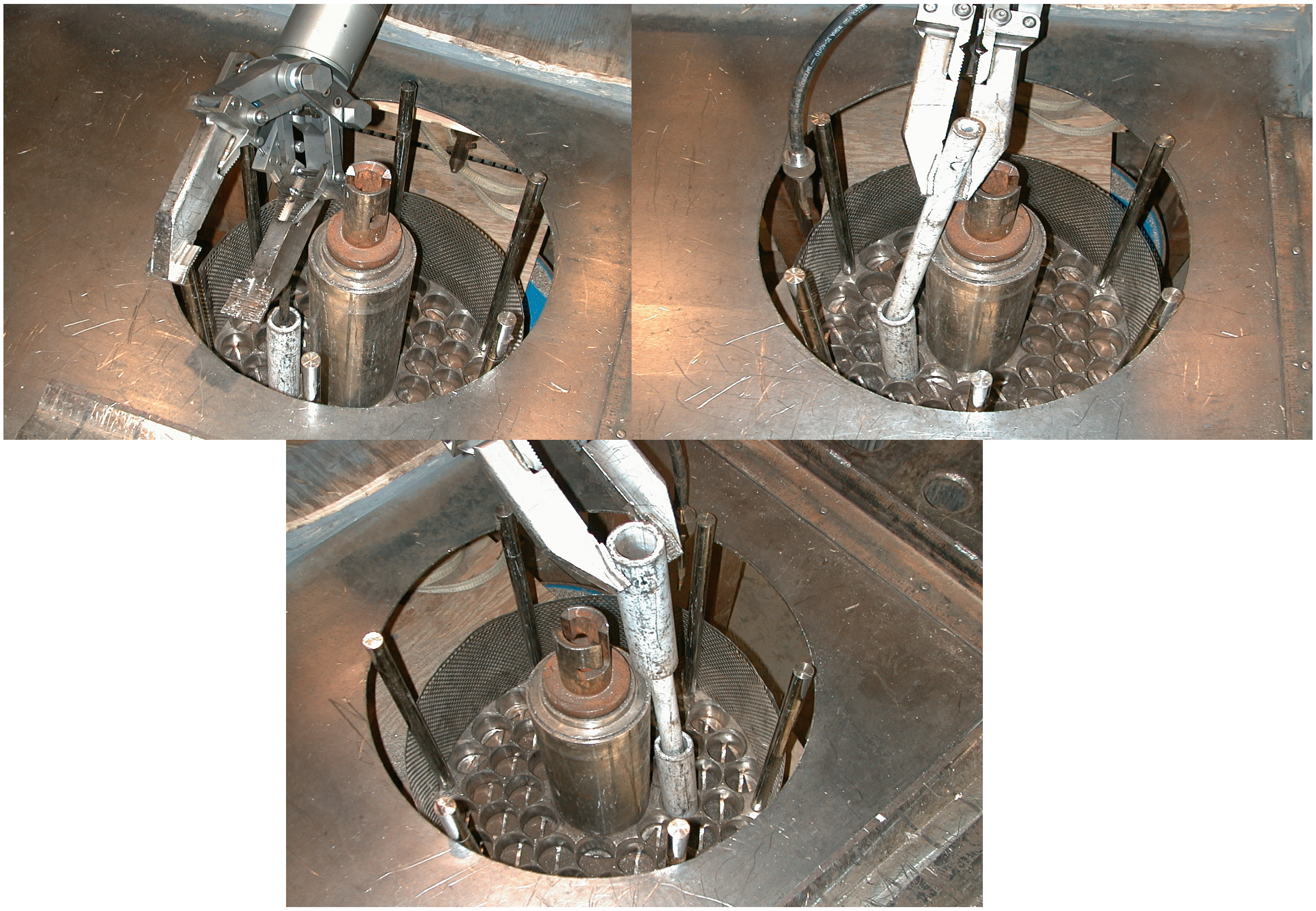

Figure 10. Loading Broken Fuel Elements.

Clockwise From Upper Left: a) Loading a Short Outer Element Into the MCO Fuel Basket; b) Loading a Full length Inner Element into a Short Outer Element; and c) Loading a Short Outer Element Onto the Full Length Inner Element.

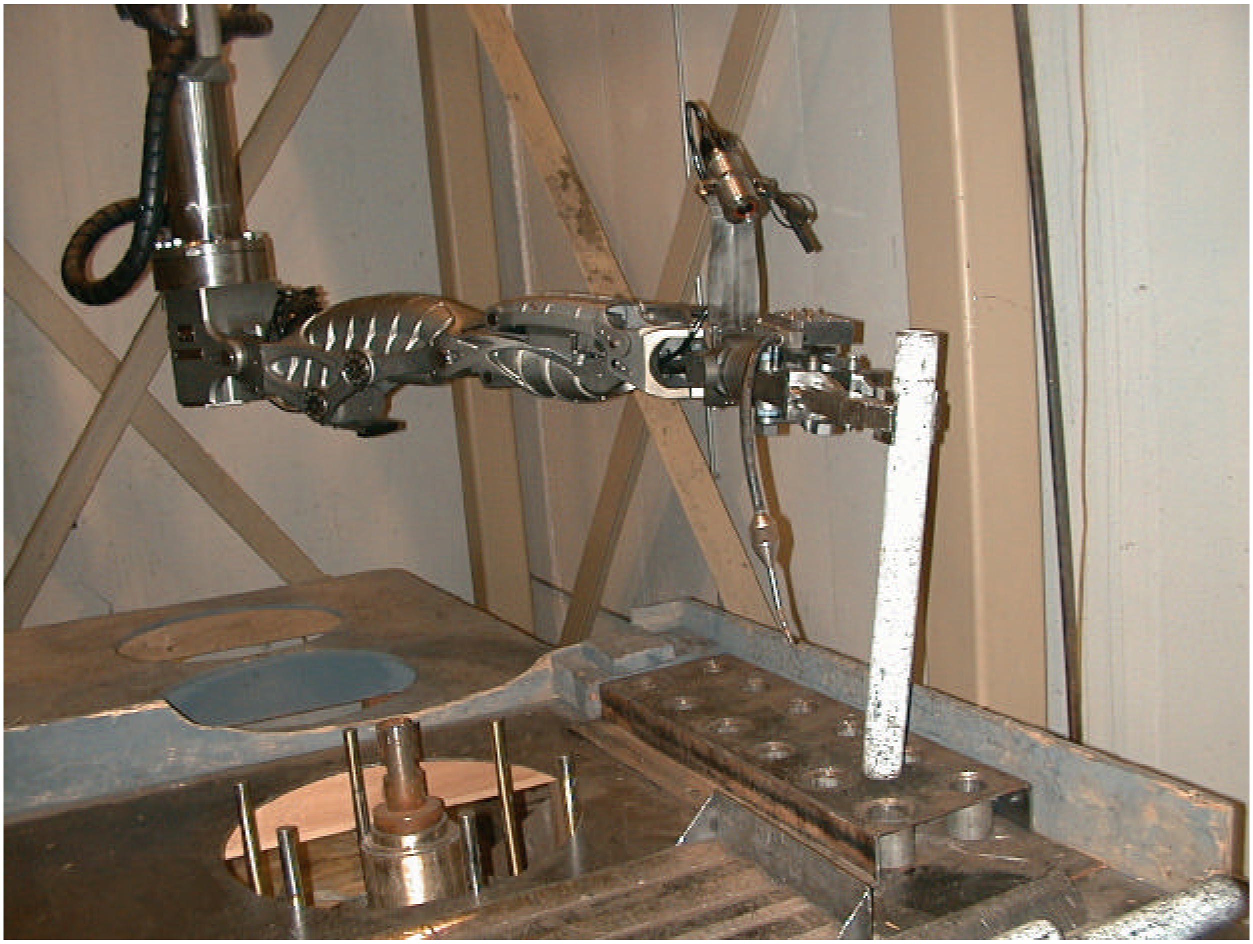

Figure 11. Gaging an Outer Element in the Go/No-Go Gage.

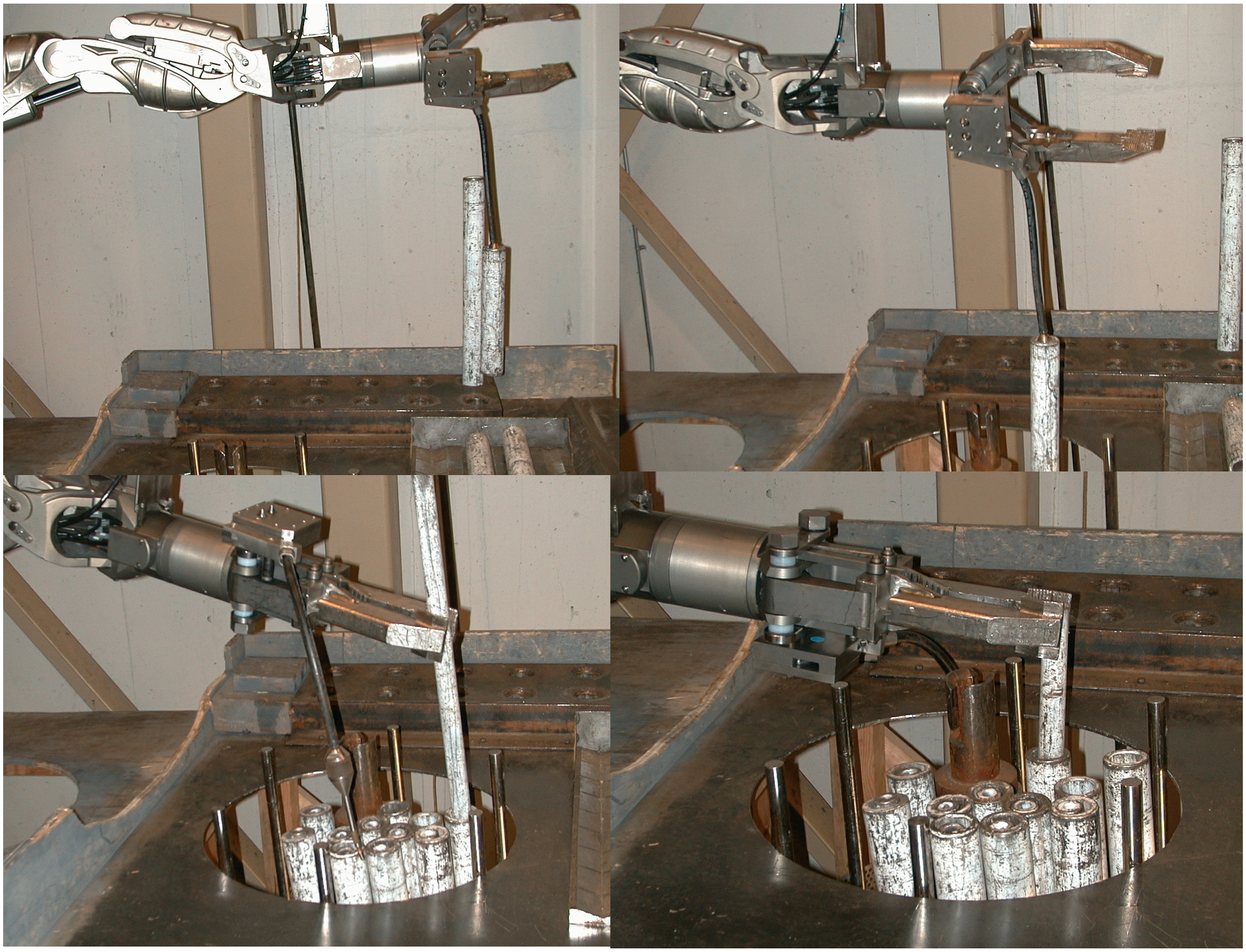

Figure 12. Loading Fuel into the MCO Fuel Basket.

Clockwise from Top Left: a) Picking a Short Outer Fuel Element up Out of the Go/No-Go Gage; b) Loading an Outer Fuel Element Into MCO Fuel Basket; c) Loading a Short Inner Fuel Element Into an Outer Fuel Element in MCO Fuel Basket; and d) Loading a Full Length Inner Element Into an Outer Element in the MCO Fuel Basket.

Test Results and Recommendations

Test Results

Equipment Validation

Equipment validation testing included five process runs. In addition to the canister process times being acceptable, ranging from 1 hour 4 minutes to 1 hour 54 minutes and an average time of 1 hour 30 minutes, the equipment performed all process steps in all cases both successfully and satisfactorily.

Process Validation – Production Mode

It was affirmed during process validation testing that the best process throughput times occurred using the dual manipulator approach. Using dual manipulators rather than a single unit for production was promoted as a result of earlier development testing. During process validation testing, in production mode, the average time to load a Mark IA fuel basket (48 Assemblies) using the dual manipulator approach was 4 hours, while the single manipulator approach produced an average production time of 6 hours and 16 minutes.

Process Validation – Validation Mode

The dual manipulator approach was also used during validation mode testing, with an average basket loading time of 4 hours 56 minutes. Some additional time should be expected during actual operations, as it was impossible to exactly imitate the validation inspection process.

TABLE 2. Average Production Test Results from Cold Validation Testing.

Average Production Test Results		
Mode of Operation	Average Canister Processing Times (Hours:Minutes)	Average MCO Basket Loading Time (Hours:Minutes)
Production Mode – Dual Manipulator	1:23	4:00
Production Mode – Single Manipulator	1:33	6:16
Validation Mode – Dual Manipulator	1:44	4:56

A Mark IA fuel basket was used in all the validation tests. The Mark IA basket holds 48 assemblies, whereas a Mark IV basket holds 54. Based on the production test results for the Mark IA, it is estimated that it would take approximately 4-1/2 hours to completely load a Mark IV basket, with its additional six assemblies.

Test Exceptions

A total of 20 test exceptions occurred during testing, however, in all but two cases testing was quickly resumed after correcting the problem. The majority of the test exceptions were associated with a cursor lock problem in the control software where the control PC had to be re-booted to correct the problem. Specifically, in these cases the test clock was kept running while the control system was re-booted. This was done to simulate actual conditions in the field should the cursor lock not be able to be eliminated from the software. In cases where support equipment failed or the system suffered a readily correctable case of infant mortality, the test clock was stopped to allow time for correcting the condition then restarted and the test run resumed after the exception was recorded in the data table. All occurrences of this type were determined to be short-term problems that were able to be permanently corrected or would be highly unlikely to occur or halt production during fuel repackaging operations. Examples of these are a power supply failure in the master control unit (MCU); a leaking seal in the pitch joint actuator; a pitch joint control problem (faulty wiring harness); having to adjust the cable tension on the fuel stinger; fuel stinger tool wouldn't fit inside the dummy fuel element; and failure of the modified Peters tool. The complete table of test exceptions is included in Appendix D.

In all, the cursor lock problem accounted for nine exceptions and the unrelated pitch joint control problem accounted for an additional four. In the latter case the problem was an intermittent problem traced down to a pinched, or smashed, wiring harness that required on line diagnostics to find. Once found, the faulty harness was replaced and testing resumed without further occurrences. The remaining test exceptions were able to be immediately corrected and did not pose a permanent threat to long term operability of the system, therefore testing was simply continued to completion. The cursor lock problem has subsequently been eliminated as a result of warranty work performed by the manufacturer. A complete mechanical refurbishment of the manipulators was also performed by factory technicians and followed by a two-week reliability test run, which essentially duplicated the production mode of the CVT. No equipment or control system failures occurred.

In addition to the 20 test exceptions, two test requirements from the test procedure were dropped from CVT. These were dropped by the test director to adapt to the conditions of the test set up and to data gathered during other tests.

The first requirement dropped from CVT, stated in Table 2 in the CVT procedure (Reference 4), was to perform single manipulator testing using each the north manipulator and the south manipulator, respectively. However, the test was only performed using the north manipulator. The south manipulator test was dropped because the north manipulator cannot be parked in a position that allows the fuel to be transported to the table from the PCM and still be accessible to the south manipulator for handling. The north manipulator is actually sitting directly in the load path for any material movement and would have to be moved manually south to dump a canister, then north to retrieve and separate the fuel using the south manipulator. This situation is created because the north manipulator cannot be moved north beyond the PCM due to the mast elevation extending below the elevation of the PCM. In addition, moving a canister while the north manipulator is parked up against the PCM cannot be accomplished because the hoist load path is directly in line with the manipulator and the load cannot "jump" the manipulator (would require hoisting the fuel canister out of the water). There are only two ways to use the south manipulator to process fuel in a solo production mode. One is to have the north manipulator completely removed from the basin and risk the possibility of having to alter the control system to allow the system to function as a single manipulator system[1]. The second is to manually move the north manipulator south to make room to dump a canister, then manually move it back north to make room for the south manipulator to retrieve and separate the fuel. Time constraints, testing deadlines, and presumed low added value were the primary drivers for not performing either of these described process alterations during CVT. This situation existed in our test mockup and also exists in the basin.

The second requirement dropped from CVT, described in Section 3.1 of the CVT procedure (Reference 4), was to transfer the loaded MCO fuel baskets and scrap baskets to the mockup MCO basket queue. This test process was dropped from CVT for two major reasons. One was because the mockup rail supports blocked the load path for transfer of a scrap basket to the queue table and the second was that the grapple intended to transport the baskets, or an acceptable prototype, was unavailable for use during CVT. An alternate method for transferring the fuel basket could have been used, but the similarity to the real system would have been so minute that the test director determined the data collected would have been relatively useless and not realistically comparable to the actual system being used in the basins.

Conclusions

The test data collected during CVT combined with test observations fully support the conclusion that the FRS manipulator system is suitably able to perform the required process functions it was designed for. It is also postulated that the manipulator system will readily provide a method for achieving superior throughput volume when compared to manual tool methods for fuel re-packaging.

Recommendations

As a result of CVT and associated pre-CVT burn-in, several recommendations for possible system improvement were formulated and are listed in TABLE 3. Although the recommendations are based on improving the manipulator system, acting on any single recommendation would not significantly alter the conclusions or throughput times indicated in this report, but would generally provide a more robust, reliable, and user-friendly system. This list of recommendations was transmitted to FRS project management under a separate cover letter in January 1999 while a few of these were in the process of being implemented.

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[1] If the control system required any adjustment or modification, it would only be required if one of the two slave controllers was unable to provide telemetry communication through the telemetry chain. This is why the single manipulator operation is still possible using the north manipulator and parking the south manipulator against the south hard stop, assuming the slave controller is still communicating through the telemetry chain. No specific tests were performed in this area as of this writing, however, they are likely to be performed informally at a later date. Using the north manipulator only will still result in potential load transport issues for loaded fuel baskets moving south to the queue tables.

In addition to the following list, several recommendations were reported in the interim equipment report[1], issued in November 1998. A final version of the equipment report is scheduled for release in September 1999 and will cover general system burn-in activities on both the K-West and K-East manipulator systems and provide greater detail covering a longer period of time than the CVT report. The equipment report also provides a more detailed discussion of the technical issues and background information concerning system reliability. This information was not included as part of the CVT report in an attempt to contain the scope of CVT within its intended boundaries and to prevent the possibility of conflicting conclusions from future reports.

[1] SUMMARY EQUIPMENT REPORT - FRS Cold Operations, Interim Version, Rev. C; PNNL, October 30, 1998, GR Kiebel, DR Jackson.

TABLE 3. Recommended Changes to Manipulator System Installation.

Item No.	Description	Priority[1]	Explanation
1 A	Add Hydraulic Fuses to Individual Manipulator Supply on SRS Dist. Manifold.	1	Reduces Risk of Major Hyd. Spill In the case of a major joint failure downstream the fuses prevent continual pumping of hydraulic fluid into the basin. These are standard on the other in-pool equipment supply manifolds.
B	Add Double Isolation (ball) Valves to Individual Manipulator Supply on SRS Dist. Manifold.	2	Reduces Potential Downtime Would allow maintenance and repair work on individual manipulator while hydraulic system remained powered.
C	Add a Pilot Operated Solenoid Valve to Individual Manipulator Supply on SRS Dist. Manifold that operates from EOC.	3	Allows Quick Operator Switching to secure one or the other manipulators from the hydraulic feed.
2	Add Hydraulic Fluid Sampling Station @ HPU.	1	Normal Maintenance Enhancement Clean access for fluid sampling was not included in HPU design by manfacturing.
3	Put Manipulator Slave Controller Power Cycle Switch in EOC.	2	Reduces Potential Downtime Does not require a second party out on the deck to cycle power.
4	Add a Ball or Check Valve to Chiller Reservoir Fill Line.	4	Normal Maintenance Enhancement Prevents fluid siphoning when refilling or topping off the reservoir.
5	Adjust HPU Installation to Allow Sight Glass to be Easily Seen.	2	Normal Maintenance Enhancement The sight glass is located on the back of the HPU and must be used regularly to check reservoir fluid levels.
6	Replace Std. Slave Controller Cover with Plexiglass Cover.	4	Normal Maintenance Enhancement Allows for quick and easy access to slave controller PC board status LED's.
7	Add Hour Meters to Each Manipulator Slave Controller (ISO Valve Control) and the HPU.	4	Normal Maintenance Enhancement Mfg. maintenance recommendations are mostly based on machine hours.
8	Modify Slave Controller Mounting Brackets (for access).	3	Normal Maintenance Enhancement Allows for easier slave controller removal and replacement.
9	Add a Quick Connector to Mast to Slave Controller Umbilical Cable.	2	Normal Maintenance Enhancement Greatly reduces risk in terminating wiring on the slave controller terminal block. Current tagging system is "fragile" at best and it is very difficult to terminate wires accurately.
10	Add Hydraulic Quick Connectors to Bridge Drive Motors.	3	Normal Maintenance Enhancement Allows for quicker, easier slave controller removal.

[1] Priority values from 1 – 4: 1-required; 2-should do; 3-preferred but not required; 4-to cheap and simple not to do.

TABLE 3. Recommended Changes to Manipulator System Installation (continued)			
Item No.	**Description**	**Priority[1]**	**Explanation**
11	Change Bridge Drive Motor Mounting Bolts to Studs.	2	Normal Maintenance Enhancement Greatly reduces the risk of dropping the mounting bolts into the pool when changing the motors out. Current configuration is cumbersome and difficult to handle. Difficulty will increase when using PPE (rubber gloves).
12	Add a Pendent Mounted Control Switch for the Stuck Fuel Element Ram Control.	2	Ergonomics Issue (EOC) Prevents operator from having to put down the manipulator MCU and reach for the ram control button. Specifically requested by operators.
13	Add a High Temp. Cutoff to Kill the HPU at 130°F.	2	Equipment Protection Issue Currently there is no high temperature protection for the HPU. The alarms are visual only and do not require a response to keep operating. This presents the potential for thermal breakdown of the fluid and possible equipment damage at both the HPU and the manipulators.
14	Add Chiller/HPU Operating Parameter Read Out (other than PC).	2	Equipment Protection Issue Currently there is no indication in the EOC of temperature conditions for the chiller coolant. It is possible for the local chiller high temp alarm to go off and not have any indication in the EOC. There is also no indication in EOC that chiller is operational.
15	Replace original bumper stop on south manipulator with longer stop [REF NCR#98-DESH-039].	1	Equipment Protection Issue Per NCR, the modified bumper stop is required to protect the bridge cameras.
16	Add GFCI protection to basin e-stop pendants.	1	NEC Requirement
17	Rework extended PA Jaw attachments to prevent bearings from slipping out.	1	Prevents jaw bearings from falling out and having to pull the manipulator out of the water for replacement.

[1] Priority values from 1 – 4: 1-required; 2-should do; 3-preferred but not required; 4-too cheap and simple not to do

References

1. Ketner, G.L. June 1997. “Interim Report Spent Nuclear Fuel Retrieval System Fuel Handling Development Testing”, PNNL-11423, Pacific Northwest National Laboratory, Richland, Washington.

2. Jackson, D.R.. September 1997. “Final Report Spent Nuclear Fuel Retrieval System Fuel Handling Development Testing”, PNNL-11666, Pacific Northwest National Laboratory, Richland, Washington.

3. Kiebel, G.R.. April 8, 1998. "Fuel Retrieval Sub-Project Process Description", HNF-2529, Rev. 0, EDT 621125, Pacific Northwest National Laboratory, Richland, Washington.

4. Kiebel, G.R. and Jackson, D.R. May 26, 1998. "FRS Cold Validation Test Procedure", SNF-2710, Rev. 0, EDT 621104, Pacific Northwest National Laboratory, Richland, Washington.

5. Kiebel, G.R and Jackson, D.R. October 30, 1998. "Summary Equipment Report – FRS Cold Operations", Interim Version, Rev. C, Pacific Northwest National Laboratory, Richland, Washington.

Bibliography

Short S.M., S. Brewe, and G. Kugler. March 22, 1996. "*Spent Nuclear Fuel Project Integrated Testing Strategy*", WHC-SD-SNF-CM-004, Rev. 0, Westinghouse Hanford Company.

Jackson D.R. April 9, 1998. "*Test Plan and Strategy for the Fuel Retrieval Sub-Project*", HNF-SD-SNF-TP-027, Rev. 2, Westinghouse Hanford Company.

Appendix A

Test Data

Equipment Validation Test Data **Dual Arm, Standard Canister Test Run**

Run No.	Operation Description	Operator	Start Time	Finish Time	Elapsed Time	Standard Canister Process Time
EV-1	North Arm: Sort Fuel, Load Scrap	2	7:53	8:35	0:42	
	South Arm: Load Fuel	1	7:54	8:57	1:03	
						1:04
EV-2	North Arm: Sort Fuel, Load Scrap	3	9:17	9:42	0:25	
	South Arm: Load Fuel	4	9:18	10:14	0:56	
	South Arm: Load Fuel		13:05	14:02	0:57	
						1:54
EV-3	North Arm: Sort Fuel, Load Scrap	2	14:11	14:37	0:26	
	South Arm: Load Fuel	1	14:12	16:05	1:53	
						1:54
EV-4	North Arm: Sort Fuel, Load Scrap	4	8:10	8:37	0:27	
	South Arm: Load Fuel	3	8:12	8:44	0:32	
	South Arm: Load Fuel	3	9:05	9:48	0:43	
						1:17
EV-5	North Arm: Sort Fuel, Load Scrap	3	10:31	10:57	0:26	
	South Arm: Load Fuel	4	10:33	11:52	1:19	
						1:21

Average Fuel Sorting, Scrap Loading Time (Arithmetic Mean)	0:29
Average Fuel Loading Time (Arithmetic Mean)	1:28
Average Standard Canister Processing Time (Arithmetic Mean)	1:30

Operator Key

Team No.	Operator No.	
Team #1	#1	Bob Crow
	#2	Ron Lorenzen
Team #2	#3	Don Benson
	#4	Tim VanReenan

Process Validation Test Data **Production Mode; Single Manipulator (North)**

Run No.	Operation Description	Operator	Start Time	Finish Time	Elapsed Time	Canister Process Time	MCO Basket Loading Time
PVPMS-1	North Arm: Sort & Load Can #1		7:51	8:47	0:56		
			8:51	9:45	0:54	1:50	
	North Arm: Sort & Load Can #2		9:46	11:14	1:28	1:28	
	North Arm: Sort & Load Can #3		11:14	12:51	1:37	1:37	
	North Arm: Sort & Load Can #4		12:51	14:11	1:20	1:20	
							6:15
PVPMS-2	North Arm: Sort & Load Can #1	1 & 2	14:41	17:33	2:52	2:52	
	North Arm: Sort & Load Can #2	4	17:33	18:49	1:16		
		4	7:17	8:07	0:50	2:06	
	North Arm: Sort & Load Can #3	3 & 4	8:07	9:36	1:29	1:29	
	North Arm: Sort & Load Can #4	3	9:36	10:22	0:46		
		3	10:25	10:45	0:20	1:09	
							7:36

Process Validation Test Data **Production Mode; Single Manipulator (North)**

Run No.	Operation Description	Start Time	Finish Time	Elapsed Time	Canister Process Time	MCO Basket Loading Time
PVPMS-3	North Arm: Sort & Load Can #1	11:05	11:35	0:30		
	Down Time	11:35	11:49	0:14		
	North Arm: Sort & Load Can #1	11:49	12:35	0:46	1:16	
	North Arm: Sort & Load Can #2	12:35	14:25	1:50	1:50	
	North Arm: Sort & Load Can #3	14:25	15:51	1:26	1:26	
	North Arm: Sort & Load Can #4	15:51	16:39	0:48	0:48	5:20
PVPMS-4	North Arm: Sort & Load Can #1	7:19	8:59	1:40	1:40	
	North Arm: Sort & Load Can #2	8:59	10:51	1:52	1:52	
	North Arm: Sort & Load Can #3	10:51	12:24	1:33	1:33	
	North Arm: Sort & Load Can #4	12:24	13:07	0:43	0:43	5:48

Average Fuel Canister Processing Time (Arithmetic Mean)	1:33
Average Mark IA MCO Fuel Basket Loading Time (Arithmetic Mean)	6:16

Process Validation Test Data **Production Mode; Dual Manipulator**

Run No.	Operation Description	Start Time	Finish Time	Elapsed Time	Operation Description	Start Time	Finish Time	Elapsed Time	Canister Process Time	MCO Basket Loading Time
PVPMD-1										
	North Arm: Sort Can #1	12:54	13:20	0:26	South Arm: Load Can #1	12:56	13:52	0:56	0:58	
	Set Up Can #2	13:20	13:27	0:07						
	North Arm: Sort Can #2	13:27	14:08	0:41	South Arm: Load Can #2	13:52	14:59	1:07	1:32	
	Set Up Can #3	14:08	14:18	0:10						
	North Arm: Sort Can #3	14:38	14:56	0:18	South Arm: Load Can #3	15:01	15:41	0:40	1:03	
	Set Up Can #4	14:56	15:01	0:05						
	North Arm: Sort Can #4	15:01	15:19	0:18	Restart #3 and Load #4	15:53	17:10	1:17	2:09	$\boxed{4:16}$

Process Validation Test Data **Production Mode; Dual Manipulator**

Run No.	Operation Description	Start Time	Finish Time	Elapsed Time	Operation Description	Start Time	Finish Time	Elapsed Time	Canister Process Time	MCO Basket Loading Time
PVPMD-2	North Arm: Sort Can #1	7:25	7:48	0:23	South Arm: Load Can #1	7:26	7:48	0:22	0:23	
	Down Time	7:48	11:11	3:23	Down Time	7:48	11:11	3:23		
	North Arm: Sort Can #1	11:11	11:47	0:36	South Arm: Load Can #1	11:11	12:07	0:56		
	Set Up Can #2	11:47	11:50	0:03						
	North Arm: Sort Can #2	11:50	12:14	0:24	South Arm: Load Can #2	12:07	13:03	0:56	1:13	
	Set Up Can #3	12:14	12:17	0:03						
	North Arm: Sort Can #3	12:17	12:40	0:23	South Arm: Load Can #3 & #4	13:03	14:47	1:44	2:30	
	Set Up Can #4	13:08	13:11	0:03						
	North Arm: Sort Can #4	13:13	13:29	0:16						$\boxed{3:59}$

Process Validation Test Data **Production Mode; Dual Manipulator**

Run No.	Operation Description	Start Time	Finish Time	Elapsed Time	Operation Description	Start Time	Finish Time	Elapsed Time	Canister Process Time	MCO Basket Loading Time
PVPMD-3										
	North Arm: Sort Can #1	12:21	12:42	0:21	South Arm: Load Can #1	12:22	13:41	1:19	1:20	
	Set Up Can #2	12:42	12:46	0:04						
	North Arm: Sort Can #2	12:46	13:09	0:23	South Arm: Load Can #2	13:41	14:34	0:53	1:52	
	Set Up Can #3	13:09	13:13	0:04						
	North Arm: Sort Can #3	14:28	14:48	0:20	South Arm: Load Can #3	14:35	15:27	0:52	0:59	
	Set Up Can #4	14:48	14:52	0:04						
	North Arm: Sort Can #4	14:53	15:08	0:15	South Arm: Load Can #4	15:28	16:08	0:40	1:20	3:47

Average Fuel Canister Processing Time (Arithmetic Mean)	1:23
Average Mark IA MCO Fuel Basket Loading Time (Arithmetic Mean)	4:00

Process Validation Test Data **Validation Mode; Dual Manipulator**

Run No.	Operation Description	Operator	Start Time	Finish Time	Elapsed Time	Canister Process Time	MCO Basket Loading Time
PVVM-1	North Arm: Sort Can #1	1	12:23	13:12	0:49		
	South Arm: Load Can #1	2	12:24	13:21	0:57	0:58	
	Dump Can #2	3 & 4	13:15	13:18	0:03		
	North Arm: Sort Can #2	4	13:18	13:43	0:25		
	South Arm: Load Can #2	3	13:22	14:32	1:10	1:17	
	Dump Can #3	1 & 2	13:42	13:45	0:03		
	North Arm: Sort Can #3	4	13:45	14:17	0:32		
	South Arm: Load Can #3	3	14:32	15:57	1:25		
		4	15:57	16:03	0:06	2:21	
	Dump Can #4	1 & 2	14:19	14:22	0:03		
	North Arm: Sort Can #4	4	14:22	14:44	0:22		
	South Arm: Load Can #4	4	16:03	16:07	0:04		
		3	16:08	16:58	0:50	2:39	
							4:35

Operator Key

Team No.	Operator No.	
Team #1	#1	Bob Crow
	#2	Ron Lorenzen
Team #2	#3	Don Benson
	#4	Tim VanReenan

Process Validation Test Data

Validation Mode; Dual Manipulator

Run No.	Operation Description	Operator	Start Time	Finish Time	Elapsed Time	Canister Process Time	MCO Basket Loading Time
PVVM-2	North Arm: Sort Can #1	3	7:17	7:52	0:35		
	South Arm: Load Can #1	4	7:18	8:36	1:18	1:19	
	Dump Can #2	1&2	7:53	7:56	0:03		
	North Arm: Sort Can #2	3	7:56	8:17	0:21		
	South Arm: Load Can #2	4	8:36	9:03	0:27		
		4	9:13	9:58	0:45		
		1	10:04	10:19	0:15	2:07	
	Dump Can #3	1&2	8:18	8:21	0:03		
	North Arm: Sort Can #3	3	8:37	8:58	0:21		
	South Arm: Load Can #3	1	10:19	11:46	1:27	3:12	
	Dump Can #4	1&2	8:58	9:01	0:03		
	North Arm: Sort Can #4	2	10:04	10:29	0:25		
	South Arm: Load Can #4	1	11:46	12:33	0:47	2:32	
							5:16

Operator Key

Team No.	Operator No.	
Team #1	#1	Bob Crow
	#2	Ron Lorenzen
Team #2	#3	Don Benson
	#4	Tim VanReenan

Run No.	Operation Description	Operator	Start Time	Finish Time	Elapsed Time	Canister Process Time	MCO Basket Loading Time
PVVM-3B	North Arm: Sort Can #1	3	7:41	8:23	0:42		
	South Arm: Load Can #1	4	7:42	8:38	0:56	0:57	
	Dump Can #2				0:00		
	North Arm: Sort Can #2	3	8:23	8:38	0:15		
		3	9:52	10:01	0:09		
	South Arm: Load Can #2	4	9:52	10:47	0:55	1:10	
	North Arm: Sort Can #3	3	10:01	10:23	0:22		
	South Arm: Load Can #3	4	10:47	11:12	0:25	1:11	
	Dump Can #4		10:24	10:30	0:06		
	North Arm: Sort Can #4	1	10:58	11:12	0:14		
		1	11:28	11:44	0:16		
	South Arm: Load Can #4	2	10:47	11:12	0:25		
		2	11:26	12:40	1:14	1:53	
							4:59

Operator Key

Team No.	Operator No.	
Team #1	#1	Bob Crow
	#2	Ron Lorenzen
Team #2	#3	Don Benson
	#4	Tim VanReenan

Appendix B

Test Log

Appendix C

Test Configuration

Appendix D

Test Exceptions

Appendix E

Test Procedures

Appendix F

Fuel Makeup in K-Basin Fuel Canisters

Appendix G

Brief Summary of General FRS Process

Brief Summary of the Fuel Retrieval System and Associated Processes

The fuel retrieval system (FRS) is generally comprised of the systems required to repackage the K-Basin fuel into multi-canister overpack (MCO) fuel and scrap baskets. This includes the grapples and hoists required to lift and transport the fuel canisters, the underwater camera system used to view underwater operations, a system to remove canister lids (K-West only), a fuel cleaning machine (PCM), a canister slitting system (FRS Stuck Fuel Station), an underwater work table, and the manipulator systems. These combined systems make up the FRS, where the intent of the manipulator system is to allow the operators to handle fuel from a remote location whereby personnel exposure to radiation is greatly reduced.

The basic operation begins by recovering an existing fuel canister from its current storage location in the basin. The canister is then transported to the decapping station (for K-West only), where the canister lids are removed. The decapper includes a confinement box, which is used to capture the plume of liquor expected to be released when the lids are removed. Captured liquor is pumped from the confinement box to a filtration system where the radioactive contamination is removed and the water recycled back to the basin.

After the lids have been removed the canister is moved to the fuel cleaning station called the primary clean machine (PCM). The PCM is very much like a top-loading washing machine, where the items to be cleaned are placed inside, the machine's lid gets closed, then the internal basket is agitated to scrub the product clean. For our fuel, the entire canister is set into an internal basket in the PCM. This basket holds the canister in the upright position and will prevent it from moving during the wash cycle. The wash cycle in the PCM rotates the internal basket so that the fuel canister rolls end-over-end in the PCM. As a result of this action, the fuel slides out of the canister by as much as four inches and then slides back again as the canister is rotated vertically again, thus causing a rubbing and sucking action. This action is combined with a high-pressure water spray being directed into the top of the open canister to perform the complete cleaning process. As with the decapping system, the resulting dirty water is suctioned out a drain and sent to the filtration system.

Once the fuel has been cleaned the canister is moved to the process table, where the fuel is dumped out onto the work surface. From here the operators use the manipulators to sort and load the fuel into the MCO baskets. The sorting process is used to separate smaller fuel pieces from larger ones and to separate out any debris material not intended for packaging in the MCOs. The pieces that are to small too load into a fuel basket go into a scrap basket instead. The scrap baskets still go into the MCO; they just have minor differences in their design to accommodate dissipation of more heat than the fuel baskets are required to. Also included in the process table operations is the inspection of at least one canister per day, which is inspected to confirm that the fuel is being cleaned to the base standard. The manipulators are also used to move the fuel to the inspection station.

The fuel is loaded into the fuel baskets in a vertical orientation. This orientation is much more favorable to drying in a vacuum chamber, which is performed on the loaded baskets after they are loaded into the MCO. Once the MCO is loaded and its contents vacuum dried, the MCO is sealed and transported to the interim storage facility, called the Canister Storage Building, or CSB. The fuel, packed into the MCOs will be stored here in the CSB until a permanent repository is opened and ready to receive the material for permanent disposal.

Appendix H

Basic Process System Diagrams

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